INTEGRATION OF ARTIFICIAL INTELIGENCE CONTROL TO THE NEURAL NETWORK BASED UNIFIED POWER QUALITY CONDITIONER

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Abstract— **The application of artificial intelligence is growing fast in the area of power electronics and drives. The artificial neural network (ANN) is considered as a new tool to design control circuitry for power-quality (PQ) devices. In this paper, the ANN-based controller is designed for the current control of the shunt active power filter and trained offline using data from the conventional proportional-integral controller. A digital-signal-processor-based microcontroller is used for the real-time simulation and implementation of the control algorithm. An exhaustive simulation study is carried out to investigate the performance of the ANN controller and compare its performance with the conventional PI controller results. The system performance is also verified experimentally on a prototype model developed in the laboratory.**

Keywords— Artificail intelligence (AI), artificial neural network (ANN), CSI, proportional integral (PI), unified power-quality conditioner (UPQC), VSI.

Introduction

The use of electronic controllers in the electric Power-supply system has become very common. These Electronic controllers behave as nonlinear load and cause serious Distortion in the distribution system and introduce unwanted Harmonics in the supply system, leading to decreased efficiency of the power system network and equipment connected in the Network. To meet the requirements of harmonic regulation, Passive and active power filters are being used in combination with the conventional converters. Presently, active power Filters (APFs) are becoming more affordable due to cost reductions in power semiconductor devices, their auxiliary parts, and integrated digital control circuits.

In addition, the APF also Acts as a power-conditioning device which provides a cluster of Multiple functions, such as harmonic filtering, damping, isolation And termination, load balancing, reactive-power control for Power-factor correction and voltage regulation, voltage-flicker Reduction, and/or their combinations. Resent research focuses on use of the universal power quality conditioner (UPQC) to Compensate for power-quality problems.

The performance of UPQC mainly depends upon how accurately and quickly reference signals are derived. After efficient extraction of the distorted signal, a suitable dc-link current regulator is used to derive the actual reference signals. Various control Approaches, such as the PI, PID, fuzzy-logic, sliding-mode, Predictive, unified constant frequency (UCF) controllers, etc., Are in use. Similar to the PI conventional controller, the PID controller requires precise linear mathematical models, which are difficult to obtain, and fails to perform satisfactorily under parameter variation nonlinearity load disturbance, etc.

Modern control theory-based controllers are state feedback Controllers, self-tuning controllers, and model reference adaptive Controllers, etc. These controllers also need mathematical Models and are therefore sensitive to parameter variations. In recent years, a major effort has been underway to develop new and unconventional control techniques that can often augment or replace conventional control techniques. A number of unconventional Control techniques have evolved, offering solutions to many difficult control problems in industry and manufacturing Sectors. Unlike their conventional counterparts, these unconventional Controllers (intelligent controllers) can learn, remember, and make decisions.

Artificial-intelligence (AI) techniques, particularly The NNs, are having a significant impact on power-electronics Applications. Neural-network-based controllers provide fast dynamic response while maintaining the stability of the converter System over a wide operating range and are considered as a new tool to design control circuits for PQ devices. Over the last few years, major research works have been carried out on control circuit design for UPQCs with the objective of obtaining reliable control algorithms and fast response procedures To obtain the switch control signals.

In this Paper, for improving the performance of a UPQC, a multilayer Feed forward-type ANN-based controller is designed for the current Control of the shunt active filter instead of the conventional PI controller. An algorithm for training the ANN controller is Developed and trained offline. Various simulation results are Presented and verified experimentally, and compare the performance Of the ANN controller with conventional PI controller Results. A DSPbased microcontroller is used for the real-time Simulation and implementation of the control algorithm.

CONFIGURATION

A conventional UPQC topology consists of the integration of two active power filters are connected back to back to a common dc-link bus. A simple block diagram of a typical UPQC is

shown in Fig. 1

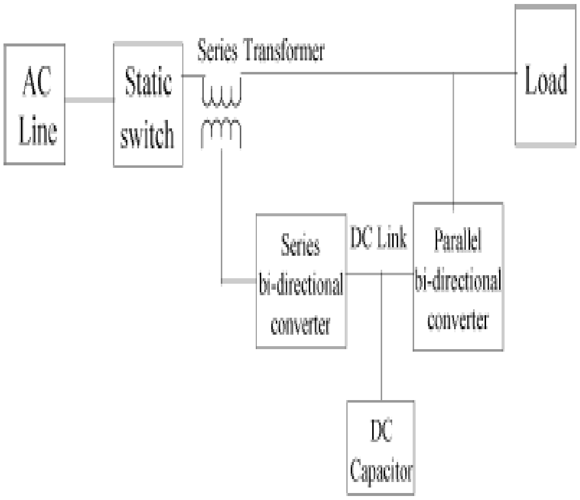


Fig.1.Block diagram of a UPQC.

can be configured either with voltage-source converters or current source converters in single phase, three-phase three wire, Or three-phase four-wire configurations. The UPQC with The voltage-source converter (VSC) is most common because Of its smaller size and low cost. Despite these previously mentioned Advantages, the VSI topology has slow control of the Converter (LC filter) output voltage and no short-circuit/over current Protection. When the active rectifier inside the UPQC is used as a power factor corrector, dc bus voltage oscillations appear which makes the control of the series filter output voltage more difficult.

The CSI-based UPQC has advantages of excellent Current control capability, easy protection, and high reliability Over VSI-based UPQ. The main drawback of the CSI-based UPQC has been so far the lack of proper switching Devices and large dc-side filter. The new insulated-gate bipolar Transistors (igbts) with reverse blocking capability are being launched in the markets which are suitable for the CSI-based UPQC. With the use of SMES coils, the size and losses can be reduced considerably. A configuration of UPQC using two current-source converters connected back to back through a large dc-link reactor is shown in Fig. 2.

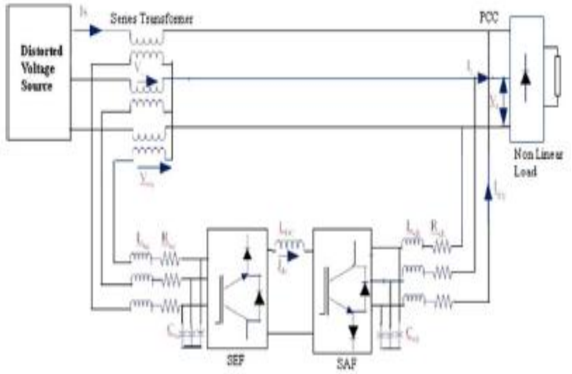


Fig.2.UPQC topology using current-source converters.

The performance of the UPQC mainly depends on how accurately And quickly the reference signals are derived. After efficient Extraction of the distorted signal, a suitable dc-link current Regulator is used to derive the actual reference signals. A dc Current regulator will serve as power-loss compensation in the Filter circuits, which will take place through the activation of A shunt unit. This regulator will maintain dc-link current constant for stable operation of the filter.

In the conventional PI Controller, the error between the actual dc-link current and a reference Value, which is generally slightly greater than the peak of the dc-link value, is fed to the PI controller. The output of the PI controller is added suitably for the generation of a reference template.

DESIGN OF THE PI CONTROLLER

Since the dc-link current is controlled by the shunt filter, the Following basic equations are used for designing the control System:

$$i_s = i_L - i_{\mathrm{inj}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$i_{\mathrm{inj}} = u_2 i_{\mathrm{dc}} \qquad \ldots\ldots\ldots\ldots\ldots (2)$$

$$L_{sh}\frac{d_{\mathrm{inj}}}{\mathrm{dt}} = v_L - i_{\mathrm{inj}} R_{sh} = v_L - v_{sh}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In order to control the filter current $(\mathrm{i_{inj}})$, the only control Variable is the duty cycle of the PWM converter $(\mathrm{u_2})$. The Problem of control is to determine the duty cycle in such a way that the dc-link current $\mathrm{i_{dc}}$ remains constant and to produce Suitable filter current to cancel the load current harmonics. This Filter current should be opposite of the harmonic current, which

Is split into two components (i.e., one loss component plus the Reactive component and another harmonic component). The Energy transfer to the continuous side takes place only at the Fundamental frequency to compensate all of the losses in the PWM converter).

Thus, it is required to control two outputs, Namely $\mathrm{i_{dc}}$ and $(\mathrm{i_{inj}})$ from one control variable (i.e., the duty Cycle of the PWM converter). However, the main objective is To control the filter current, and the control strategy must lead To precise compensation of the harmonic component. The value Of $\mathrm{i_{dc}}$ needs to only be approximately constant and there is no Dynamic performance to be attained. The more it is constant, the more linear the system will be. Hence, $(\mathrm{i_{inj}})$ is controlled indirectly by processing the actual source current and estimated Reference current in a hysteresis current controller. These Reference currents are estimated by regulating dc-link current. In order to estimate the steady-state error in the dc-link current, A PI controller is used. Although the dynamic response of the Dc-link inductor has no effect on the compensation feature of the scheme, a mathematical model is required for the stability Analysis and, hence, for determining the parameters of the PI Controller. The following assumptions are made for deriving the mathematical model of the system.

1) The voltage at PCC is sinusoidal and balanced.

2) Since the harmonic component does not affect the average power balance expressions, only the fundamental component of currents is considered.

3) Losses of the system are lumped and represented by an equivalent resistance $\mathrm{R_{sh}}$ connected in series with the filter inductor $\mathrm{L_{sh}}$.

4) Ripples in the dc-link current are neglected.

The block diagram of the current control loop is shown in Fig. 3, where G gain of the PI controller; $\mathrm{K_c}$ transfer function of the PWM converter.

A linear model of the PWM converter can be derived by applying a small-signal perturbation technique to obtain its transfer function. In this method of deriving a linear model,

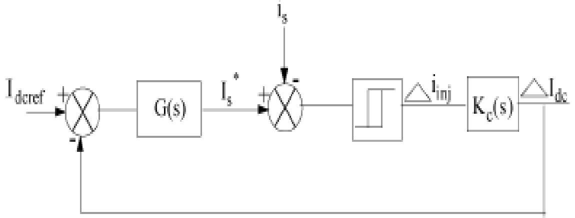


Fig.3.Block diagram of the current control loop.

The system is assumed to operate in the steady state, and the Defining equations are linearized for small-signal perturbation. The relation between the input (ac side) and output (dc-link Side) quantities of the pwm converter are obtained by equating the rate of change of energy associated.

- The average rate at which energy being absorbed by the inductor is

$$P_{\mathrm{ind}} = \frac{d}{\mathrm{dt}}\left(\frac{1}{2}L_{\mathrm{DC}}I_{\mathrm{DC}}^2\right) = L_{\mathrm{DC}}I_{\mathrm{DC}}\frac{dI_{\mathrm{DC}}}{\mathrm{dt}}. \quad \text{…………………} (4)$$

- The power input to the PWM converter

$$P_{\mathrm{conv}} = 3v_{sh}i_{\mathrm{inj}}. \quad \text{………………..} (5)$$

- The average rate of change of energy associated with the capacitor filter

$$P_{\mathrm{cap}} = 3\frac{d}{\mathrm{dt}}\left(\frac{1}{2}c_{sh}v_{sh}^2\right). \quad \text{…………………} (6)$$

Power loss in the resistor $\mathrm{R_{sh}}$

$$P_{\mathrm{loss}} = 3i_{\mathrm{inj}}^2R_{sh}. \quad \text{………………..} (7)$$

Equating the average rate of change of the change of energy

$$P_{\mathrm{ind}} = P_{\mathrm{Conv}} - P_{\mathrm{loss}} - P_{\mathrm{cap}} \quad \text{……………..} (8)$$

On substituting the values from (4)–(8)

$$L_{\mathrm{dc}}I_{\mathrm{dc}}\frac{dI_{\mathrm{dc}}}{\mathrm{dt}} = 3\left[v_{sh}i_{\mathrm{inj}} - i_{\mathrm{inj}}^2R_{sh} - \frac{d}{\mathrm{dt}}\left(\frac{1}{2}c_{sh}v_{sh}^2\right)\right]$$

Or

$$L_{\mathrm{dc}}I_{\mathrm{dc}}\frac{dI_{\mathrm{dc}}}{\mathrm{dt}} = 3v_{sh}i_{\mathrm{inj}} - i_{\mathrm{inj}}^2R_{sh} - v_{sh}c_{sh}\frac{dv_{sh}}{\mathrm{dt}} \quad \text{…….} (9)$$

In order to linearize the power equation, a small perturbation $\Delta\mathrm{i_{inj}}$ is applied in the input current of converter $\mathrm{i_{inj}}$ about a steady-state operating point $\mathrm{i_{injo}}$, the average dc-link current will also get perturbed by a small amount $\Delta\mathrm{I_{dc}}$ around its steady-state operating point $\mathrm{I_{dcO}}$

Hence, by substituting

$$i_{\mathrm{inj}} = i_{\mathrm{injo}} + \Delta i_{\mathrm{inj}} \quad \text{and} \quad I_{\mathrm{dc}} = I_{\mathrm{dco}} + \Delta I_{\mathrm{dc}}$$

in (9), on neglecting the higher order terms

$$L_{dc}I_{dco}\frac{d}{dt}\Delta I_{dc} = 3\left(v_{sh}i_{injo} + v_{sh}\Delta i_{inj} - i_{injo}^{2}R_{sh} - 2i_{inj}\Delta i_{injo}R_{sh} - v_{sh}c_{sh}\frac{dv_{sh}}{dt}\right)$$
……………………….. (10)

The steady-state equation can be written as

$$0 = 3\left(v_{sh}i_{injo} - i_{injo}^{2}R_{sh}\right).$$
………(11)

The linear relationship between Δi_{inj} and ΔI_{dc} can be obtained By subtracting (10) from (9)

$$L_{dc}I_{dc}\frac{d}{dt}\Delta I_{dc} = 3\left(v_{sh}\Delta i_{inj} - 2i_{injo}\Delta i_{inj}R_{sh} - v_{sh}c_{sh}\frac{dv_{sh}}{dt}\right)$$
……………… (12)

The transfer function of the PWM converter for a particular operating point can be obtained from (12) as

$$K_c = \frac{\Delta I_{dc}}{\Delta i_{inj}} = 3\left(\frac{v_{sh} - c_{sh}v_{sh}s - 2i_{injo}R_{sh}}{L_{dc}I_{dco}s}\right)$$
…………………. (13)

The characteristic equation of the current control loop is used to obtain the constants of the PI regulator, which can be written as

$$1 + \left(k_p + \frac{k_i}{s}\right)\frac{3(v_{sh} - c_{sh}v_{sh}s - 2i_{injo}R_{sh})}{L_{dc}I_{dco}s} = 0.$$
…………………… (14)

The controller parameters are designed on the basis of 5% overshoot to step change in the amplitude of current reference. For the selected system with the following variables, a second-order characteristic equation is found for the closed-loop system

$$v_{sh} = 230\text{ volt},\quad I_{injo} = 5\text{ amp},\quad R_{sh} = 0.4\,\Omega,$$
$$C_{sh} = 24\,\mu F\quad L_{dc} = 160\text{ mH},\quad I_{dco} = 5\text{ amp}.$$

This characteristic equation is used to determine the components of the PI regulator. The analysis of this characteristic equation shows k_p that determines the current response and k_i defines the damping factor of the current loop. By substituting the values shown in (14), we obtain

$$1 + \left(K_p + \frac{K_i}{s}\right)\left(\frac{-0.0165s + 678}{0.8s}\right) = 0$$
……………… (15)

$$0.8s^2 + k_p(678s - 0.0165s^2) + k_i(678 - 0.0165s) = 0.$$
………………. (16)

Using Routh–Harwitz criteria for system stability, the limit of the stability region is found out for the characteristic equation shown in (16). The parameters of the PI regulator are obtained as $k_p = 0.5$ and $k_i = 10$. For the selected values of k_p and k_i in the most stable region, the transient response of the current control loop for the step change is plotted as shown in Fig. 4.

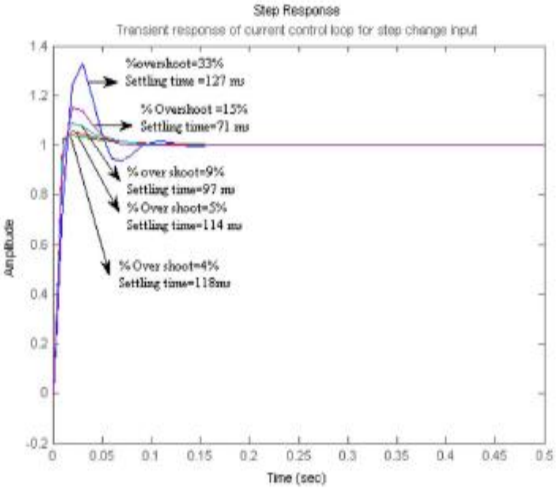


Fig.4.Transient response of the current control loop for step change.

The percentage overshoot and settling time for the selected values of k_p and k_i are tabulated as given in Table I.

TABLE I
OVERSHOOT AND SAMPLING TIME FOR DIFFERENT VALUES OF k_p AND k_i

K_p	K_i	Percentage over shoot (%)	Settling time(ms)
0.1	10	33	127
0.2	10	15	71
0.3	10	9	97
0.4	10	5	114
0.5	10	4	118

From this table, optimum values of k_p and k_i are selected as 0.5 and 10, respectively. The stability of the system thus obtained Is analyzed by using the frequency scanning technique

for the selected value of k_p , k_i and is shown in Fig. 5. As ω Varies from $-\infty$ to $+\infty$, the curve encircles the origin in an Anticlockwise direction.

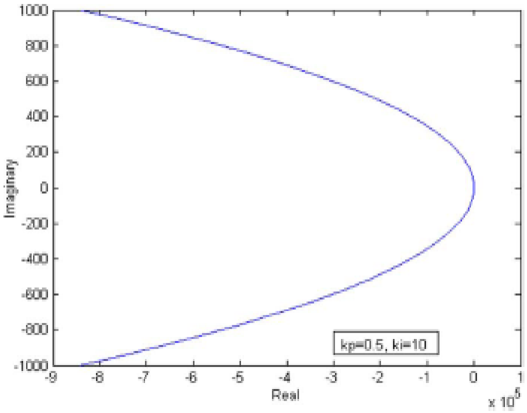


Fig. 5.Frequency scanning curve for the selected values of k_p and k_i

DESIGN OF ANN CONTROLLER

The rapid detection of the disturbance signal with high accuracy, Fast processing of the reference signal, and high dynamic Response of the controller are the prime requirements For desired compensation in case of UPQC. The conventional Controller fails to perform satisfactorily under parameter variations Nonlinearity load disturbance, etc. A recent study shows That NN-based controllers provide fast dynamic response while Maintaining stability of the converter system over wide operating Range.

The ANN is made up of interconnecting artificial neurons. It Is essentially a cluster of suitably interconnected nonlinear elements Of very simple form that possess the ability to learn and Adapt. It resembles the brain in two aspects: 1) the knowledge Is acquired by the network through the learning process and 2) Interneuron connection strengths are used to store the knowledge.

These networks are characterized by their topology, The way in which they communicate with their environment, the Manner in which they are trained, and their ability to process in- Formation. ANNs are being used to solve AI problems without Necessarily creating a model of a real dynamic system. For improving the performance of a UPQC, a multilayer feed forward- Type ANN-based controller is designed. This network Is designed with three layers, the input layer with 2, the hidden Layer with 21, and the output layer with 1 neuron, respectively.

The large data of the dc-link current for n and $(n-1)$ intervals From the conventional method are collected and are stored in The Matlab workspace. These data are used for training the NN. The activation functions chosen are tan sigmoidal for input and Hidden layers and pure linear in the output layer, respectively. This multilayer feed forward-type NN works as a compensation Signal generator. The network topology of the ANN is as shown in Fig. 6. The training algorithm used is Levenberg–Marquardt backpropagation (LMBP). The MATLAB programming of ANN

Training is given as follows:

```
net =
newff(minmax(P),[2,21,1],{'tansig','tansig','purelin'},
'trainlm');
net.trainParam.show = 50;
net.trainParam.lr = .05;
net.trainParam.mc = 0.95;
net.trainParam.lr_inc = 1.9;
net.trainParam.lr_dec = 0.15;
net.trainParam.epochs = 1000;
net.trainParam.goal = 1e − 6;
[net,tr] = train(net,P,T);
a = sim(net,P);
gensim(net,−1).
```

The compensator output depends on the input and its evolution. The NN is trained for outputting fundamental reference Currents. The signals thus obtained are compared in a hysteresis

Band current controller to provide switching signals. The block Diagram of the ANN compensator is as shown in Fig. 7.

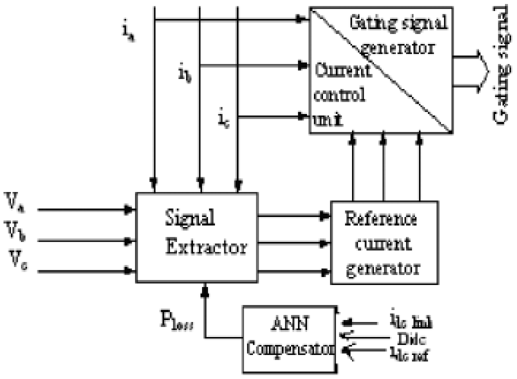


Fig. 7. Block diagram of the ANN-based compensator for offline training.

SIMULATION RESULTS

In this section, the performance comparison of PI and ANN Controllers in controlling the dc-link current of an UPQC is performed. In this comparison, the time required for stable operation at initial and load change conditions as well as the change. In load current performance are studied. The performance of the Shunt active filter of the UPQC with the PI controller is given in

Fig. 8 while that with an ANN controller is given in Fig. 9.

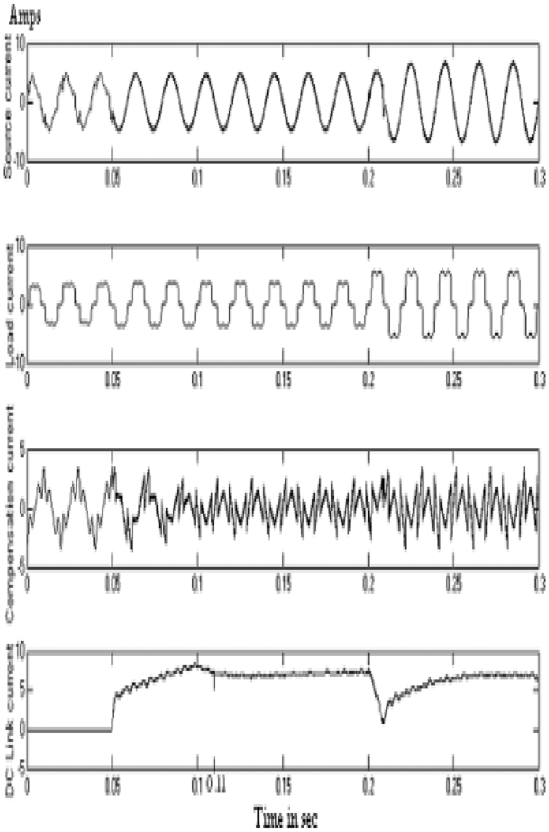


Fig. 8. Performance of the shunt active filter of the UPQC with the PI controller For load perturbations.

From Figs. 8 and 9, it is observed that in case of the PI controller, the shunt filter takes almost two-and-a-half cycles to stabilize the dc-link current at the initial condition. Also, at the load change from 5 A to 7.5 A, it almost takes a similar amount of time to reach a stable state. In case of the ANN controller, the dc-link current stabilizes within a half cycle after the start of the

shunt filter, and at the load change, it takes almost one cycle to reach its mean value, thus improving system performance.

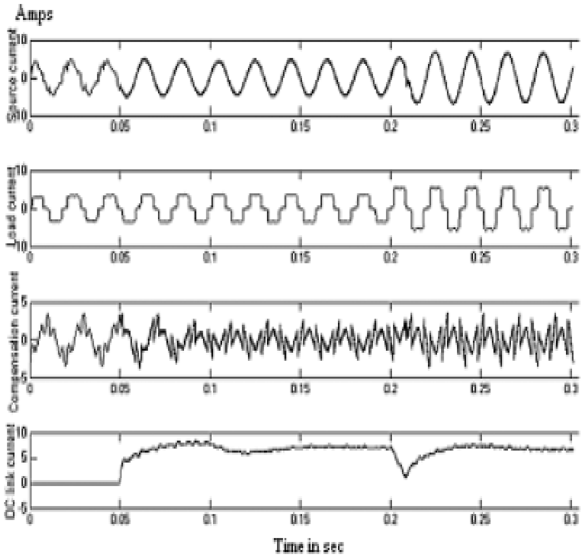


Fig. 9. Performance of the shunt active filter of the UPQC with an ANN controller for load perturbations**.**

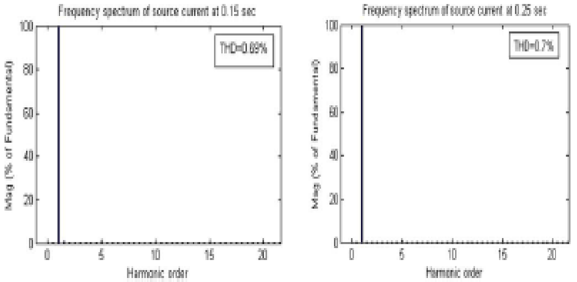


Fig.10.Frequency spectrum of the source current at different loading conditions with the PI controller.

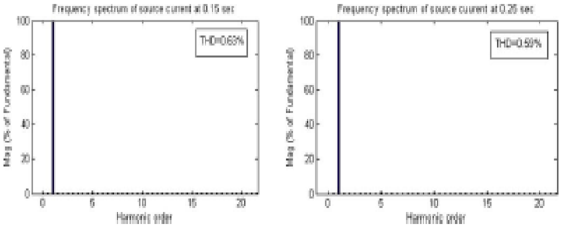


Fig.11.Frequency spectrum of the source current at different loading conditions With the ANN controller.

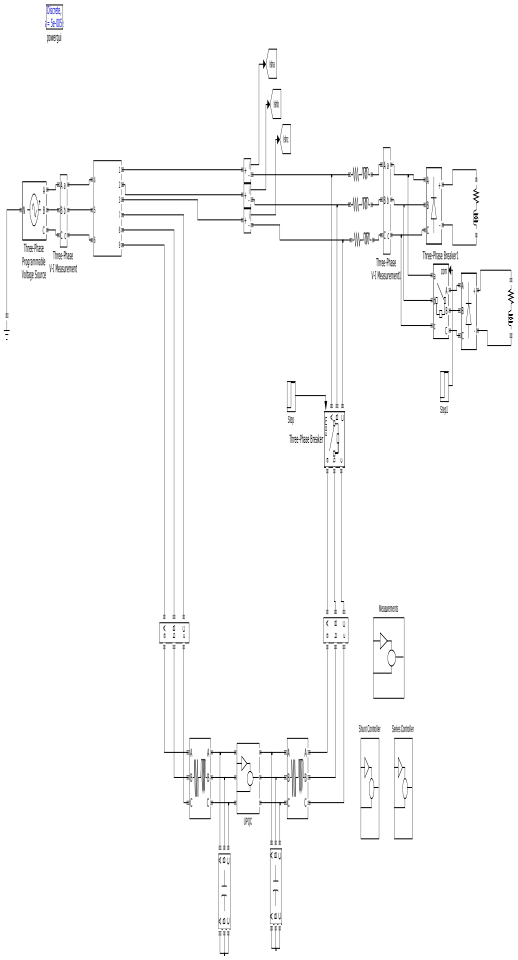
The performance of harmonic current filtration is shown in Figs. 10 and 11. The load current in both cases is found to be content of all odd harmonic minus triplen, providing a total harmonic distortion (THD) of 27.82%. It is observed from the figure that the THD of the source current at 0.15 s is 0.69% in the case of the PI controller while it is 0.63% in the case of the ANN controller scheme. Similarly, the THD of the source current at .25 s is 0.7% in case of the PI controller while it is 0.59% in case of the ANN controller scheme. Table II gives a comparison of the UPQC performance for PI and ANN controller schemes using simulation results.

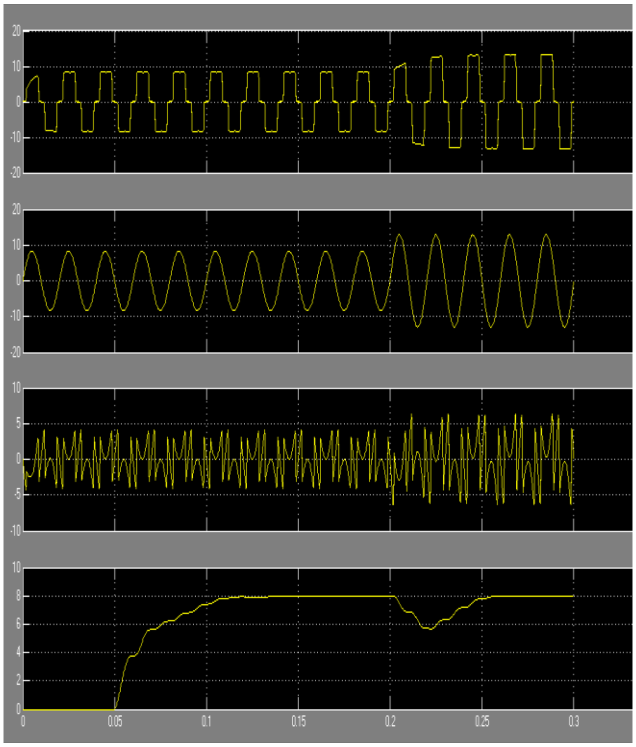
TABLE II
COMPARISON OF THE PI AND ANN CONTROLLER PERFORMANCE

Type of controller	PI	ANN
Time for stabilization at initial loading	50 ms	10 ms
Time for stabilization at load change	50 ms	35ms
Load current harmonics	27.82%	27.82%
Source current harmonics at 0.15 sec	0.69%	0.63%
Source current harmonics at 0.25 sec	0.7%	0.59%

MATLAB DESIGN OF CASE STUDY AND RESULTS

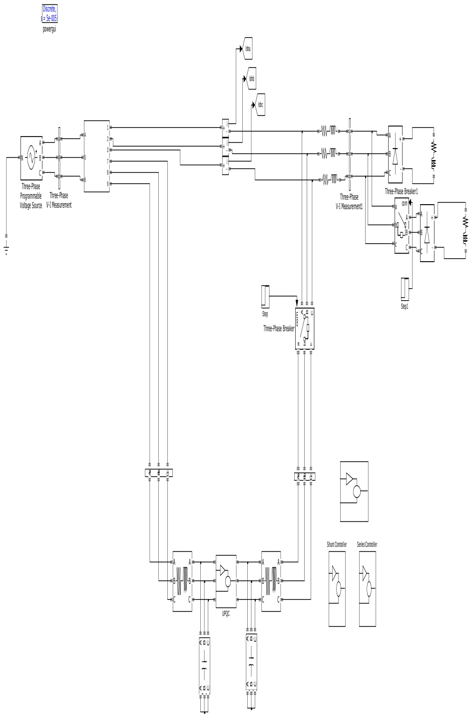
Case I: UPQC based on PI controller

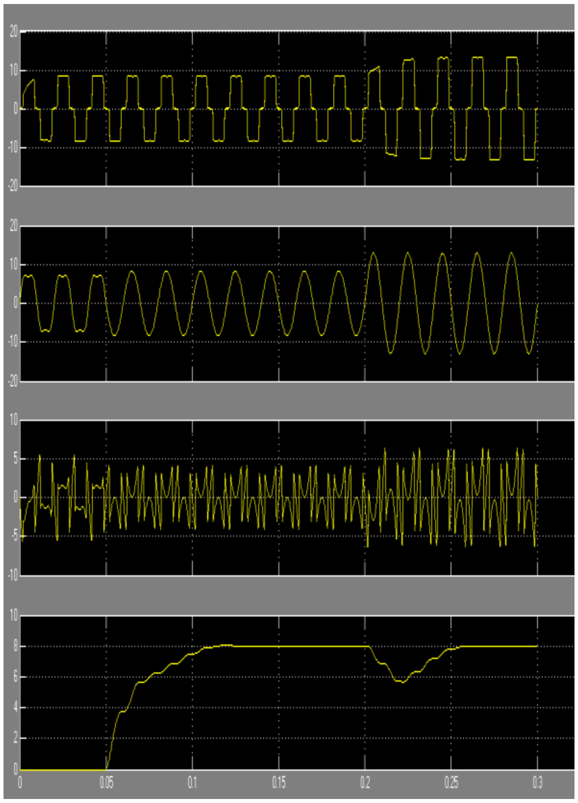




Performance of the shunt active filter of the UPQC with the PI controller for load perturbations.

Case II: UPQC based on ANN





Performance of the shunt active filter of the UPQC with an ANN controller for load perturbations.

CONCLUSION

The performance of the UPQC mainly depends upon how accurately and quickly reference signals are derived. It was observed that the power conditioner compensates for voltage as well as current harmonics. However, its performance using the conventional PI controller was not satisfactory especially With respect to transient conditions.

In order to improve its Response time, the artificial-intelligence-based ANN controller is proposed, and its performance is analyzed by simulation and experimentally. During the simulation study for obtaining satisfactory performance, the sample period was set to 1 s. However, due to the limitation of the d space controller, the sample period was Limited to 100 s only. As a result, the experimental results are found to be on the higher side compared to those of the simulated Results. Despite this, the prototype model gives satisfactory Performance for all types of loads. The performance is found to Be in close approximation with that of the PI controller results; However, there was considerable improvement in the response Time of the control of the dc-link current which is the main issue In the case of the power system network.

References

[1] e. W. Gunther and h. Mehta, “a survey of distribution system power Quality,” ieee trans. Power del., vol. 10, no. 1, pp. 322–329, jan. 1995.

[1] w. M. Grady, m. J. Samotyj, and a. A. Myola, “survey of active Power line conditioning methodologies,” IEEE trans. Power del., vol. 5, no. 3, pp. 1536–1542, jul. 1990.

[2] f. Kamron, “combined dead beat control of series—parallel converter Combination used as a universal power filter,” in proc. IEEE power Electronics specialist conf., 1995, pp. 196–201.

[3] h. Fujita and h. Akagi, “the unified power quality conditioner: the Integration of series active filter and shunt active filters,” in proc. IEEE/ Power eng. Soc. Power electronics specialist conf., jun. 1996, pp. 491–501.

[4] v. S. C. Raviraj and p. C. Sen, “comparative study of proportional integral, Sliding mode and fuzzy logic controllers for power converters,” Ieee trans. Ind. Appl., vol. 33, no. 2, pp. 518–524, mar./apr. 1997.

[5] j. H. Marks and t. C. Green, “predictive control of active filters,” in Proc. Inst. Elect. Eng. Conf. Power electronics and variable speed Drives, sep. 2000, pp. 18–23.

[6] y. Chen, l. F. Sanchez, k. M. Smedley, and g. Chen, “one-cycle controlled Unified power quality conditioner for load side voltage sag compensation,” In proc. Power electronics specialists conf., 2005, vol. 36, Pp. 282–288.

[7] r. E. King, computational intelligence in control engineering, ser. Control eng. Basel, new york: marcel dekker.

[8] a. Zouidi, Jul. 2004. f. Fnaiech, and k. Al-haddad, “neural network controlled Three-phase three-wire shunt active power filter,” in proc. Ieee isie, Montreal, qc, canada, jul. 9–12, 2006, pp. 5–10.

[9] r. El shatshat, m. M. A. Salama, and m. Kazerani, “artificial intelligent Controller for current source converter-based modular active Power filters,” IEEE trans. Power del., vol. 19, no. 3, pp. 1314–1320, jul. 2004.

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